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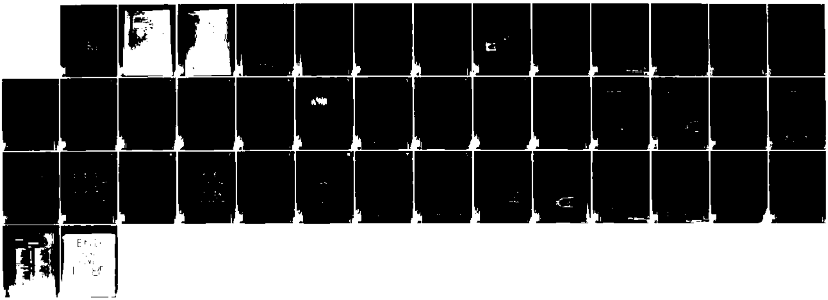

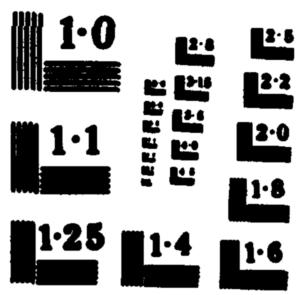
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SACLANTCEN REPORT SR-81

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DEEP WATER MASS CIRCULATION IN THE WESTERN ALBORAN BASIN: MEASUREMENTS IN JULY AND SEPTEMBER 1980 (ALBORAN I EXPERIMENT)

by

Pavel Pistek

15 July 1984

This report has been prepared as part of Project 04.

APPROVED FOR DISTRIBUTION

RALPH R. GOODMAN
Director

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DEEP WATER MASS CIRCULATION IN THE WESTERN ALBORAN BASIN: MEASUREMENTS IN JULY AND SEPTEMBER 1980 (ALBORAN I EXPERIMENT)

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ABSTRACT

The deep circulation of the Alboran Sea has been studied in a set of experiments. Two currentmeter moorings were deployed in the area. The currents at the northern site were very slow (average approx. 1 cm/s) and correlation between currents at 300 m and 800 m was poor. The currents over the Moroccan continental slope were faster (average of 2.7 cm/s), with a prevailing flow along the slope towards Gibraltar. To test an assumption that the geostrophic current is faster along the Moroccan continental slope, three floating vertical currentmeters were released and acoustically tracked for several days. This revealed that the current is faster in that area and that it accelerates towards Gibraltar. CTD and STD data showed an upward bending of isolines towards the Moroccan continental slope. Contours of salinity and potential temperature probably show the meandering upper-layer structure and not the fully developed anticyclonic gyre. Rotary spectra and autospectra of the low-frequency current velocity data show significant peaks around 2, 3 and perhaps 14 days.

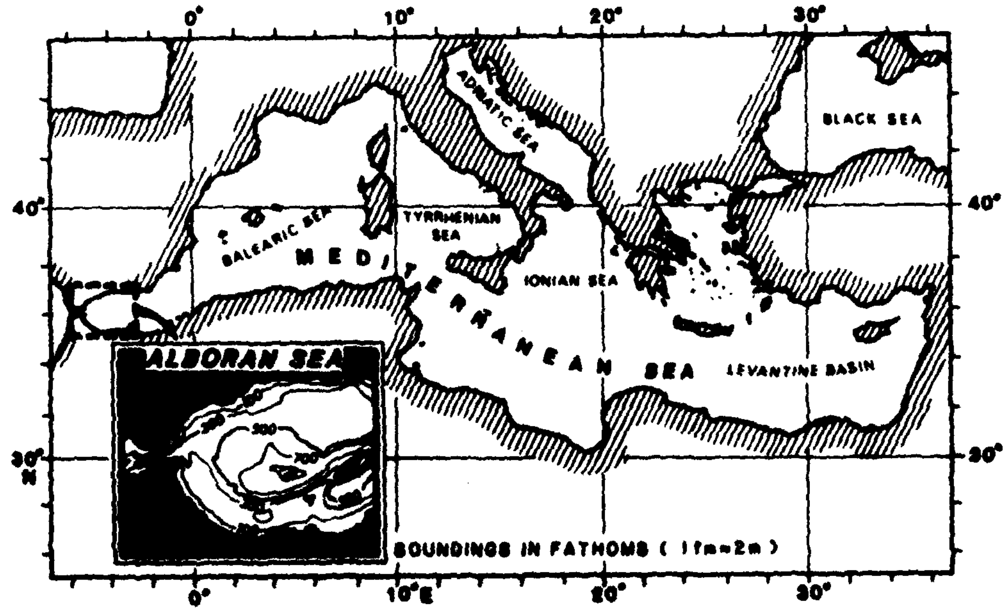


FIG. 1 THE MEDITERRANEAN SEA, SHOWING DETAILS OF THE AREA OF EXPERIMENTS IN THE ALBORAN SEA.

INTRODUCTION

The Alboran Sea (Fig. 1) is the part of the Mediterranean lying immediately to the east of the Strait of Gibraltar. This strategically important area has a complicated and variable oceanographic structure, with strong thermal fronts and eddies, a current jet, and large salinity variations, all being important for sound propagation. SACLANTCEN has therefore studied, collected, and analyzed oceanographic data that would help to describe and understand those features in the Alboran Sea and ultimately contribute to the numerical modelling of circulation in the whole of the Western Mediterranean Basin.

Seven cruises have been made to the area:

(a) Two preparatory cruises in July and September 1980 — ALBORAN I,
(b) Three cruises in winter 1982 — ALBORAN II,
(c) Two cruises in summer 1983 — ALBORAN III.

This report treats the results of (a); later reports will describe the other cruises.

The purpose of the two preparatory cruises in 1980 was to test the range of acoustical reception and the quality of the signals transmitted from acoustically tracked floats and to measure the speed and direction of the deep currents so as to establish the time and space scales of later experiments.

In addition, in cooperation with scientists from the French Laboratoire d'Océanographie Physique (J.C. Gascard, M.A. du Chaffaut, and P.F. Jeannin), free-floating vertical currentmeters were acoustically tracked in the southwestern part of the Alboran Sea to measure the deep currents near the Moroccan continental slope.

Satellite infrared imagery of the Alboran Sea has also been used in these studies. This has been facilitated by the new shipborne system developed at SACLANTCEN <1>, which gives in-situ knowledge of the sea-surface temperature, thereby allowing the experiments to be modified and improved. The numerical modelling of the surface circulation developed by Preller and Hulbert <2> was used to plan the experiments in the later stages.

1 BACKGROUND

As the Alboran Sea is part of the Mediterranean Sea, the main source of dynamical forcing for the circulation of the Alboran Sea is the gradient of gravity geopotential caused by excessive evaporation in the Mediterranean. The exchange of water and its properties, such as salt and heat, through the Strait of Gibraltar has been treated by Defant <3> and Deacon <4>. The excess of evaporation over precipitation in the Mediterranean Sea requires a net inflow into the Mediterranean to achieve a mass balance. The salt balance requires a slightly smaller bottom outflow, with the net flux being about twenty times smaller than each of the two fluxes. Bethoux <5>, <6>, estimated an inflow of 1.68 Sverdrup and an outflow of 1.60 Sverdrup (53×10^{12} m^3/year and 50.5×10^{12} m^3/year), Lacombe <7>, <8> and Lacombe et al <9> arrived at values that were 25% smaller. Bryden and Stommel <10> estimated higher inflow than Lacombe, stressing the need for more precise measurements of such an important parameter. The coriolis force, atmospheric disturbances, and mainly semi-diurnal tides modify the circulation.

The circulation in the Western Alboran Basin involves both Atlantic and Mediterranean waters. The three types of water considered are those identified by Bryden and Stommel <10>: Atlantic Water, Levantine Water, and Western Mediterranean Deep Water. The Atlantic Water forms the inflow to the Alboran Sea, and the Levantine and Western Mediterranean Deep Waters comprise the outflow of Mediterranean water through the Alboran Sea to the Atlantic.

A 150-m thick surface layer of Atlantic Water flows into the Alboran Sea as a 20-km wide jet at a speed of several knots; it has a characteristic average salinity of 36.5 and a temperature that depends on the season. Its extension and depth are quite variable. This energetic layer creates anti-cyclonic circulation in the southern part of the Western Alboran Basin. It is well documented by Lacombe <11>, Lanoix <12>, Cheney and Doblar <13>, and Gallagher et al <14>. Laboratory and numerical modelling has been reported by Whitehead and Miller <15> and Preller <2>, respectively. The layer is clearly visible on the satellite infrared images of the sea-surface temperature, as shown by Wannamaker <16>, Philippe and Harang <17>, and La Violette <18>.

Under the 150-m thick surface layer is water of Mediterranean origin. First is the intermediate Levantine water formed near Rhodes (Ozturgut <19>) and characterized throughout the Mediterranean by a mid-depth maximum in both temperature and salinity (Wüst <20>). Deeper is the Western Mediterranean Deep Water formed south of France (Medoc Group <21>), which is less saline but colder, with a potential sigma of 29.10 kg/m^3 or greater and a potential temperature of less than 12.90°C (Sankey <22>, Stommel <23>).

Only Stommel et al <24>, Porter <25>, and Bryden and Stommel <10> addressed the deep flow. From thorough CTD measurements Bryden and al <26> found faster flow near the Moroccan continental slope. Bryden and Stommel's currentmeter data <10> from the southern site showed the current directed

along the isobath towards Gibraltar, with small annual variability. This result and the sloping isolines across the Morrocan continental slope indicated the possibility of the direct outflow of Western Mediterranean Deep water from the Western Alboran Rasin to the Atlantic.

2 MEASUREMENTS AND DATA TREATMENT

2.1 Purpose

The two measurement cruises described here were made in July and September 1980 and were designed to obtain three types of information. First, to obtain information about the horizontal speed of the currents from two currentmeter moorings in different positions, each mooring carrying two currentmeters at depths corresponding to the Levantine and Western Mediterranean Deep Waters. Second, to measure the current along the slope, as predicted by Bryden and Stommel, by deploying free-floating vertical currentmeters (VCMs) near the Moroccan continental slope. Third, to test the reception quality of 1500 Hz sound signals transmitted from floats deployed at different depths and positions and received by shipborne receiving station. The last knowledge was needed for the future deploym and tracking of floats from autonomous listening stations.

2.2 Hydrography

Short hydrographic surveys were made with a CTD (Niel Brown) in July and with an STD (Grundy 9040) in September. The positions and times of the casts are shown in Fig. 2 and Table 1. The purpose of the CTD measurements made during 19-21 July was to establish the extension of the Alboran Sea gyre, with the tacit assumption that it is a permanent feature, as described in the earlier literature. The STD measurements were made during 14-16 Sep (casts 1-24) and 18-21 Sep (casts 26-46) and were concentrated in a limited area because of the need to acoustically track VCMs and to test new floats.

Continuous high-resolution profiles of salinity and temperature are important for Mediterranean studies because the variations in temperature and salinity between the Levantine and Western Mediterranean Waters are very small. Figure 3 indicates this difference for CTD cast 7. Both CTD and STD sensors were calibrated at SACLANTCEN before and after the cruises. The resolution in salinity and temperature in each cast was good enough for both the CTD and STD sensors to distinguish the variations between the water masses. The stability during the CTD measurement was better than 0.001°C and 0.002. The set of STDs had an average shift in salinity of 0.034, with individual cast variations of less than 0.004. This shift was established by comparing the salinity/potential-temperature plots of STDs with the salinity/potential-temperature diagrams of CTDs in such a way that the slopes of Western Mediterranean Deep Water were matched without shifting the potential temperature. Data from every cast were ordered progressively with depth (no return loops permitted) and the different variables computed. Data for displaying salinity and potential temperature variations were averaged to 10 m values.

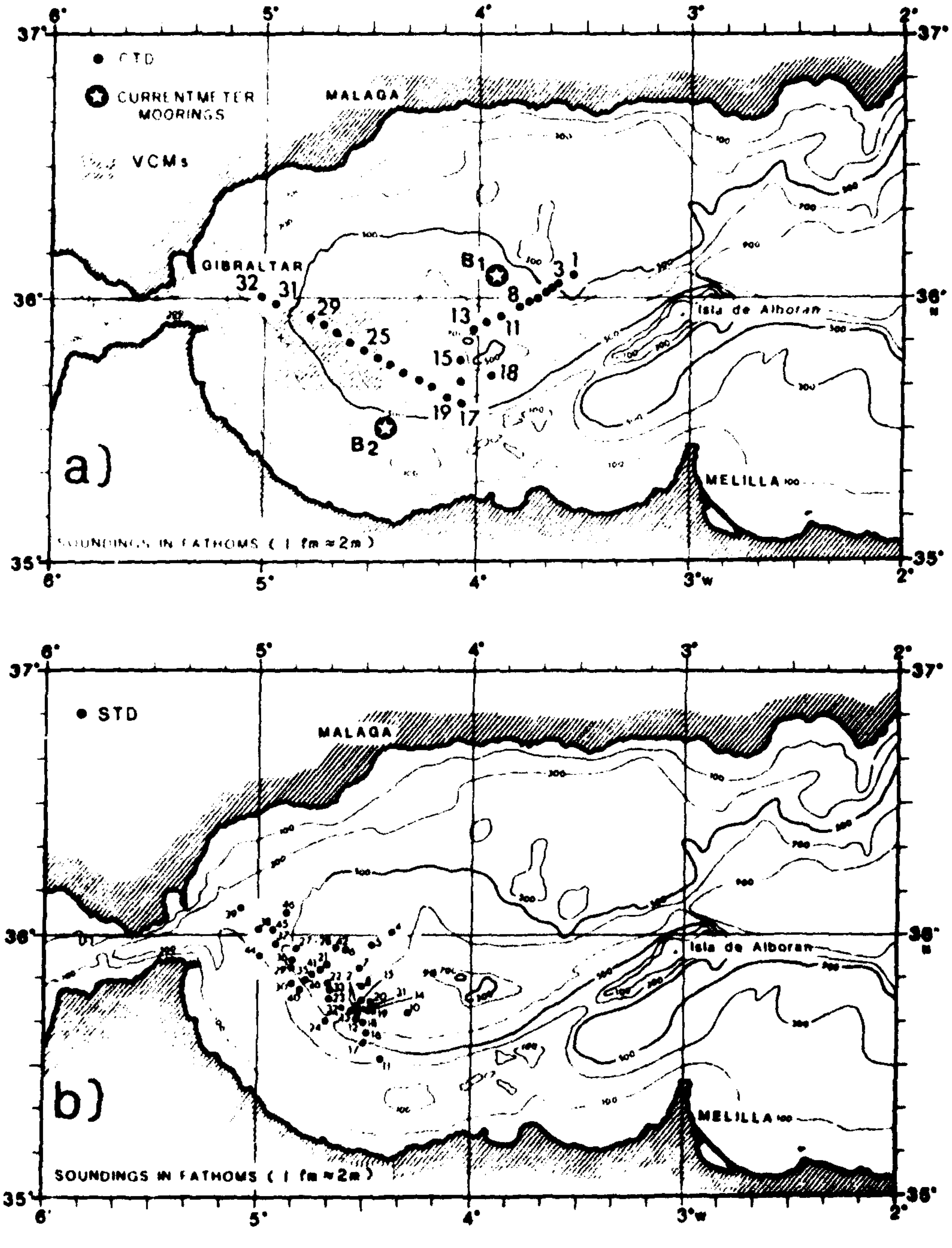


FIG. 2 DEPLOYMENT OF MEASURING INSTRUMENTS, JULY AND SEPTEMBER 1980.
a) CTD, Current meters, VCMs
b) STD

TABLE 1

INSTRUMENTS AND TIME OF MEASUREMENT

Instrument		No.	Date (1980)	Julian Days
CTD (N. Brown)		1-32	19-21 Jul	201-203
STD (Grundy 9040)	I	1-24	14-16 Sep	258-260
	II	26-46	18-21 Sep	262-265
Currentmeters (moored)				
(NBA)		B_1(320m)	19 Jul-17 Sep	201-261
(VACM)		B1(830m)	19 Jul-17 Sep	201-261
(NBA)		B_2(400m)	20 Jul-15 Sep	202-259
		B_3(500m)	18 Jul-30 Aug	200-243*
Vertical currentmeters (drifting)				
		VCM2	18-21 Sep	262-265
		VCM3	15-19 Sep	259-263
		VCM4	16-20 Sep	260-264

* Bryden's data taken for comparison (only data coincident with SACLANTCEN's measurements)

NBA - currentmeter
VACM - EG & G vector-averaging currentmeter

2.3 Currents

Two propeller-type currentmeters were deployed on each of the two moorings, whose sites are shown in Fig. 2. At mooring B1 there was an NBA currentmeter at 320 m depth and a VACM currentmeter at 830 m. At mooring B2 there was an NBA currentmeter at 400 m depth and a VACM currentmeter at 500 m. The sampling intervals were 10, 15, and 10 minutes. The VACM currentmeter at the B2 mooring stopped working after 30 days of operation.

After removing the spikes from the currentmeter data, low-pass filtering was applied and data were decimated to hourly values. Figure 4 displays the velocity vector series for this set. Groves' filter <27> was applied to remove tidal effects selectively and as a low-pass filter. Figure 5 shows the results of its application to the time series and Fig. 6 shows the resulting difference in the spectra. Tidal and inertial oscillations are clearly visible in the original spectra but filtration removed all periodicities shorter than 40 hours.

The vertical currentmeters (VCMs) used were the property of the French Laboratoire d'Oceanographie and were operated by Gascard, Jeannin and Du Chaffaut of that institute . They are incompressible free-floating devices that can be positioned at any depth in the water column and, being pressure controlled, stay almost constantly at that depth, even in areas of upwelling. Because they are cylindrical and have blades mounted around the body they rotate in proportion to the speed of upflowing currents. They were tracked acoustically by the signal transmitted from their pinger and received by two hydrophones located on each side of the Centre's research vessel MARIA PAOLINA G. This required the ship to operate at close range. The VCMs were preset to return to the surface at the end of the study for recovery by the ship.

VCMs were deployed at three locations along the Moroccan continental slope to a depth of about 800 m for 3 to 4 days. During their deployment the ship established eight positions of VCM 2 and 4 and six positions of VCM 3. The computed velocities are given in Fig. 7; these are biased by tides and inertial oscillations.

2.4 Acoustic Transmission

The investigation of the reception quality of the 1500 Hz acoustic signal transmitted from mid-range floats was part of the preparatory work for the 1982 ALBORAN II experiment. The receiver was lowered from the ship to different depths, and the transmitter, mounted on a Swallow-type float, was deployed at different ranges and depths and in various geographic settings. The received signal was compared with the exact one transmitted from the floats. The quality of the cross-correlation indicated that the optimal depth for a receiver in the Alboran environment is 400 m. In the later experiment the autonomous listening stations were moored at this depth. It was also found that the acoustical reception was good to at least 80 km from the source.

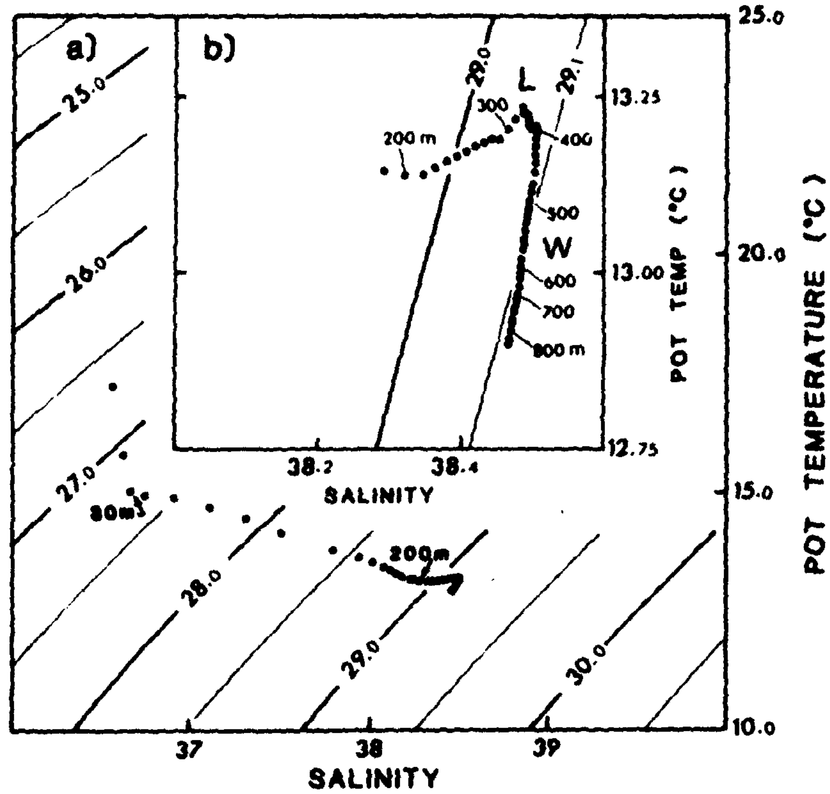


FIG. 3 SALINITY/POTENTIAL TEMPERATURE DIAGRAM WITH POTENTIAL SIGMA CURVES: THE WESTERN ALBORAN BASIN.

a) The large-scale plot shows the presence of two water masses: unmixed Atlantic Water of 36.6 salinity above 30 m depth and unmixed, more saline Mediterranean Water below about 200 m depth; between these depths is a layer of mixed water.

b) The detailed plot shows the waters of Mediterranean origin:

L) Levantine with typical temperature and salinity maxima between 300 and 400 m and

W) Western Mediterranean Deep water with the potential sigma larger than 29.10 kg/m³

(Dots mark average data point every 10 m and numbers signify the corresponding depths).

a)

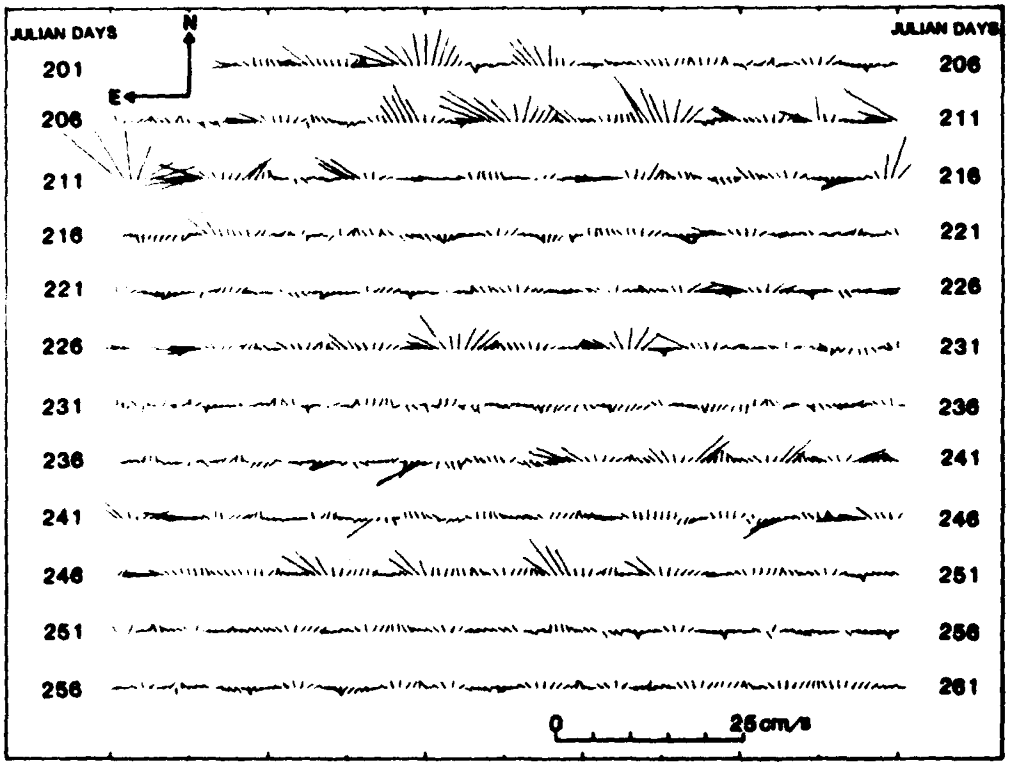
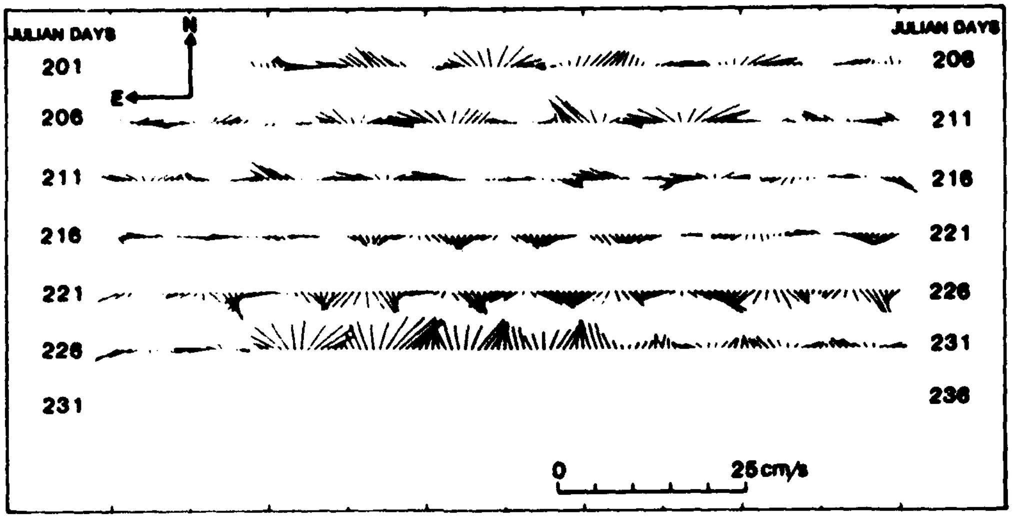


FIG. 4 VELOCITY VECTOR PLOT OF HOURLY NBA CURRENTMETER DATA, JULY AND SEPTEMBER 1980.
a) Position B_1, depth 320 m
b) Position B_2, depth 830 m
c) Position B_3, depth 400 m

b)


JULIAN DAYS
N
E
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211
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JULIAN DAYS
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226
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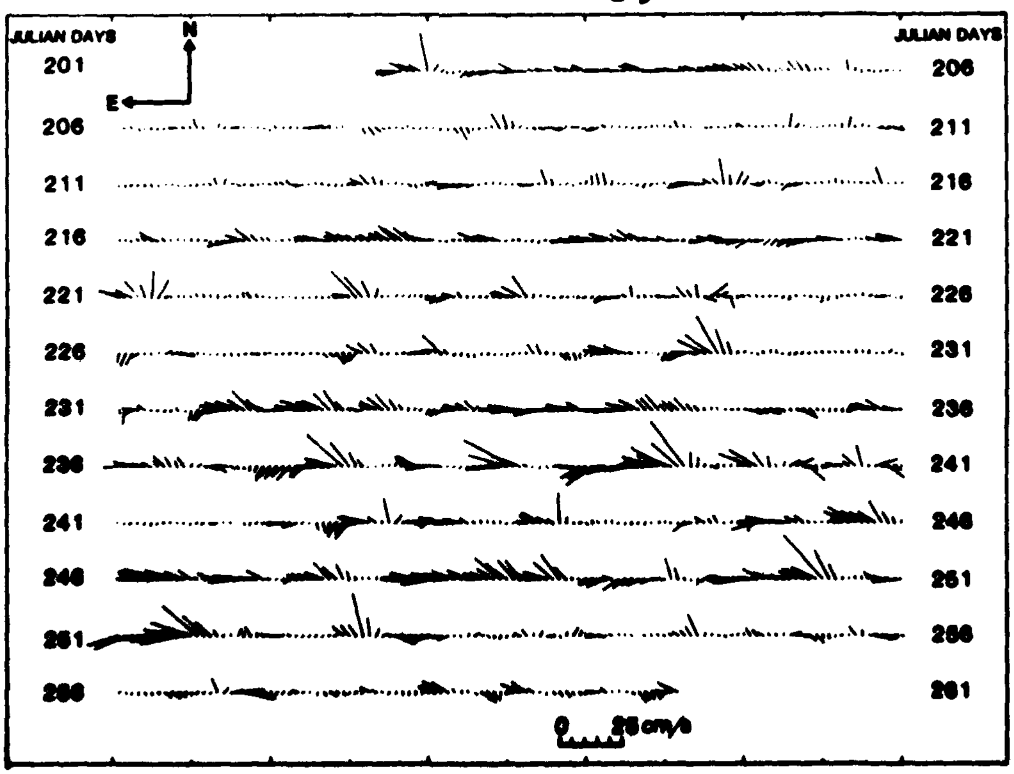
236
0
25 cm/s

c)


JULIAN DAYS
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256
261
0
25 cm/s

FIG. 4 (cont)

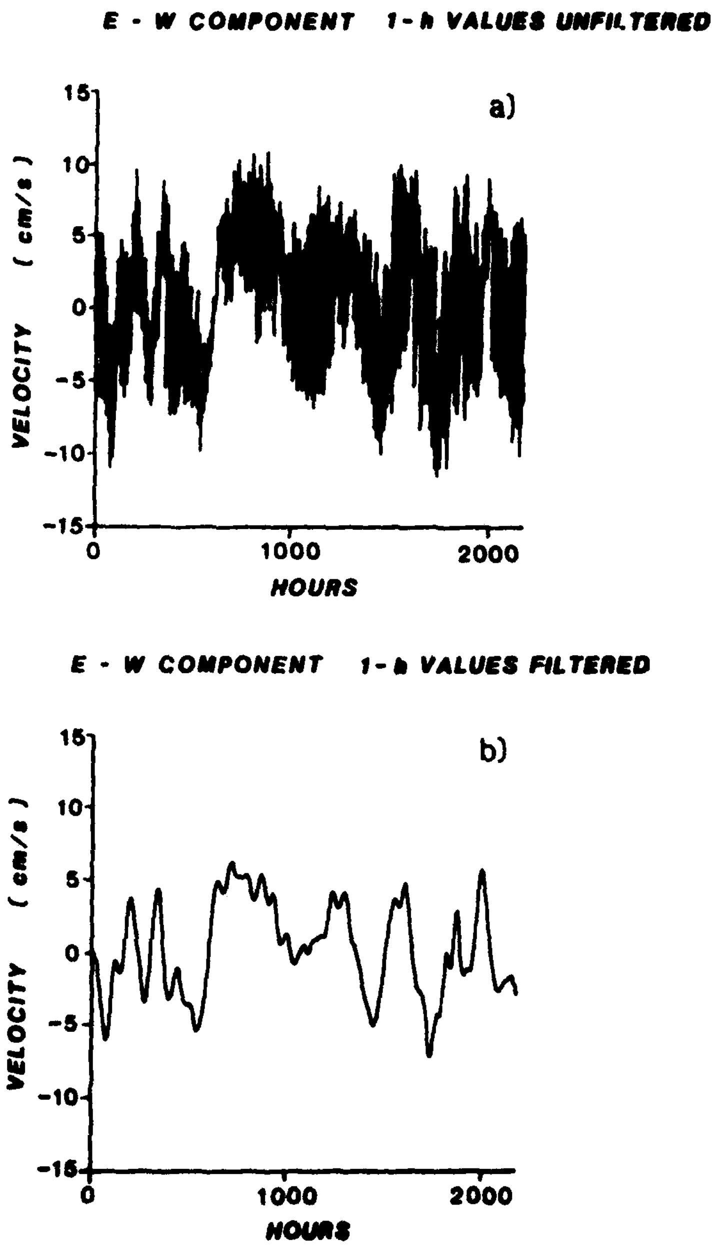


FIG. 5 EXAMPLE OF HOURLY CURRENTMETER DATA BEFORE AND AFTER FILTRATION BY GROVES' FILTER.
a) Hourly values of E-W velocity component from currentmeters, spikes indicate the semidiurnal tides.
b) Smooth version after filtration by Grove's filter.

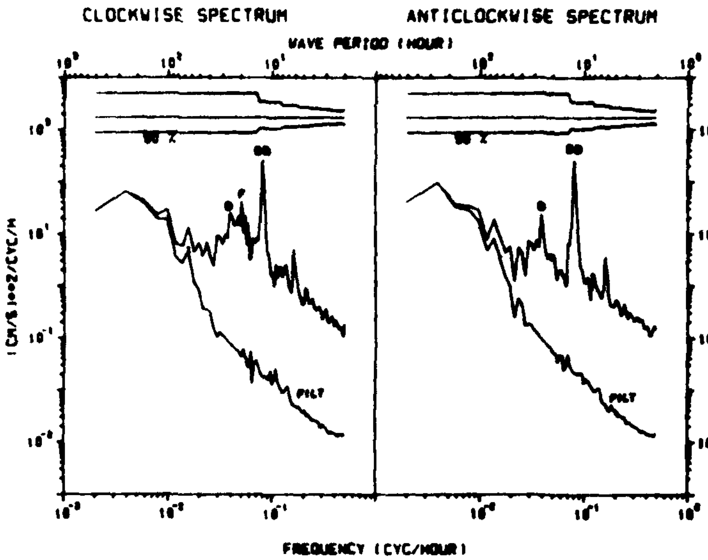


FIG. 6 EXAMPLE OF THE ROTARY SPECTRA FROM HOURLY CURRENTMETER DATA BEFORE AND AFTER FILTRATION.
Semidiurnal (SD) and diurnal (D) tides and inertial oscillations (F) are clearly visible in original data but they are subdued after filtration.

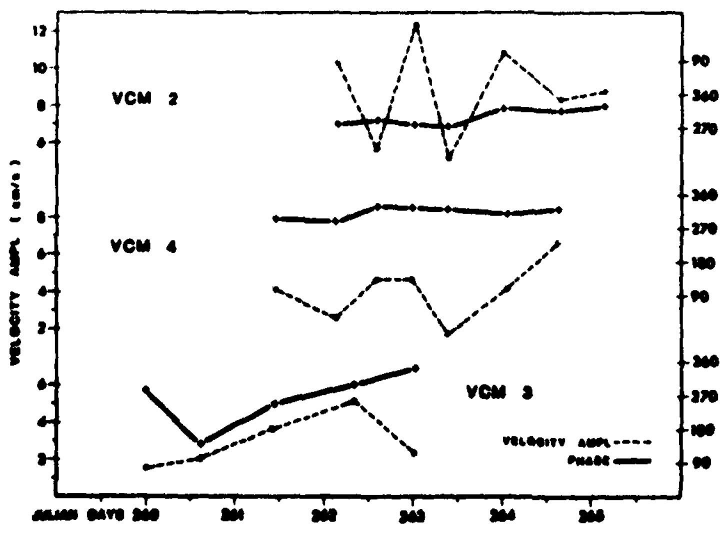


FIG. 7 VELOCITY AMPLITUDE AND PHASE FOR VERTICAL CURRENTMETERS, SEPTEMBER 1980.
Tides and inertial oscillations contribute to variations. Phase is given in degrees relative to north and is clockwise-positive.

3 RESULTS

3.1 Temperature and Salinity

A very pronounced feature in the distribution of potential temperature and salinity is that isotherms colder than 12.90°C and isohalines below the salinity maximum bend upwards towards the Moroccan continental slope. This indicates the presence of deep water of Western Mediterranean origin (Stommel <23>). To show the difference, Fig. 8 presents diagrams for two STD casts (35 and 40) separated by about 8.5 km. Water at 800 m at station 35 has the same θ-S value as water at 600 m at station 40; water at 710 m at station 35 is similar to water at 500 m at station 40. Even though the difference in depth is so large, the change of potential energy is small; this is because the potential density between Levantine and Western Mediterranean Deep Water is small. Figure 9 demonstrates the in situ density and the variation in depth of the potential density in the Alboran water; the more detailed variation of temperature and salinity of the deep water is given in Fig. 3. It is seen that a variation of 0.15 kg/m^3 in potential sigma covers all Mediterranean water (from 200 m to the bottom).

Several cross-sections of potential temperature and salinity from CTD and STD stations are shown in Figs. 10 and 11. The CTD cross-section in Fig. 10a shows that the isolines do not bend upwards towards the northern slope of the deep Alboran channel as would be expected for the Western Mediterranean Deep Water inflow. Unfortunately, cast 17 does not lie far enough south to show the conditions across the southern boundary. The CTD cross-section (casts 17 to 32) in Fig. 10b was intended to show the extension of the anticyclonic gyre at the time of deployment of the currentmeters. However, it does not show the large-scale gyre but probably shows the meandering structure and larger anticyclonic gyre situated further east, starting from cast 23 and also visible on the above cross-section between casts 13 and 17.

Several STD cross-sections were taken in Sep 1980 (Fig. 11). Again they did not extend far enough south, because of the simultaneous need to track the VCMs acoustically. However, they demonstrate the upward bending of the isolines, as first observed by Bryden and al <26>. In all three cross-sections in Fig. 11 there is a visible bending of the isolines and a quite abrupt decrease of the Intermediate Water near the Moroccan continental slope. Contours of salinity and potential temperature in the deep water (Fig. 12) obtained from these data also show the banking of deeper water against the southern slope. Contours of potential temperature, salinity, and dynamic height anomaly (relative to 200 m) in the shallow water at 50, 100 and 150 m (Fig. 13) show the meandering feature, and possibly the gyre, extended to the east. These data were taken during two periods, 14-16 Sep and 18-21 Sep, and indicate an approximately 36-km westerly movement of the meander, and probably the gyre, during a few days.

3.2 Currents

The position and results of the currentmeter measurements are presented in Fig. 14. The moored currentmeters at B1 and B2 were SACLANTCEN's. The

moored currentmeter at B_3 is the one described by Bryden and Stommel <10>, whose measurements overlapped the SACLANTCEN measurements for 40 days; its data are plotted here for comparison. The progressive vector diagrams for all currentmeters are displayed in Fig. 14b. The two currentmeters at 320 m and 830 m at mooring B_1 indicated very slow currents with average speeds of 0.7 and 1.1 cm/s, respectively. The currentmeter at 400 m at mooring B_2 showed a much stronger current, with average speed of 2.7 cm/s, flowing along the Moroccan continental slope. The 500 m currentmeter at mooring B_3 indicated a current with an average speed of 6.0 cm/s, about 2.5 times greater than that recorded at mooring B_2 during the same 40-day period but in the same direction.

The time-series of the velocity vectors for all currentmeters are given in Fig. 14c. The SACLANTCEN data are the filtered and decimated versions of hourly data sampled at 12-h intervals. The Bryden data from mooring B_3 are daily values.

VCMs tracks are also displayed in Fig. 14a. The numbers near their tracks indicate hours, starting from 0000 on 15 Sep (Julian day 259), when their locations were established by the ship. It is seen that current speeds increase towards Gibraltar and that the currents follow the line of the Moroccan continental slope, flowing towards it from the east. The average speeds of VCMs 2, 4 and 3 were 8.7, 4.0 and 3.6 cm/s, respectively. Corresponding time-series of the velocity vectors are in Fig. 14c.

The autospectra and rotary spectra of the low-frequency current velocity data are shown in Fig. 15. They are computed as an average from all three currentmeter data. The time-series were too short to give better confidence limits. The numbers near the peaks indicate the associated period in days; the most significant appear to be at 2, 3, and possibly 14 days. These may be related to atmospheric periodicities and resonances of internal modes in the Western Mediterranean Basin.

Figure 16 shows the geostrophic currents. Those in Fig. 16a were calculated from the CTD measurements made along the cross-section shown in Fig. 10b. The traditional reference level for geostrophic calculations in this region is the depth of the transition between Atlantic and Mediterranean waters, which closely follows the 14°C isotherm. If the anticyclonic circulation actually extends deeper, this setting of the reference level at 200 m results in a cyclonic circulation in the deep water. Another choice of reference level is the ocean bottom, which results in an anticyclonic gyre throughout the whole water column. As usual in geostrophic calculations, additional currentmeter measurements or the precise measurement of the surface elevation (for example by satellite altimeter) are needed to establish the proper geosotrophic velocity profile. The low current speed (as demonstrated by measurements at mooring B_1) and weak stratification in the deep water require that a very reliable set of CTD or STD measurements be used for this computation, stressing the need for a small time spread when taking the casts in the set. There are indications in Figs. 13 that the surface layer in the Alboran Sea changes appreciably in a few days. The geostrophic calculation in Fig. 16a, with the reference level at 200 m, shows the anticyclonic circulation in the upper layer, with a small meander between stations 23 to 20 and a return current in the southern part between stations 20 to 17. This feature

resembles the later, September, conditions depicted on the contours of variables in the upper layer (Fig. 13). The deeper circulation (> 200 m) shows the cyclonic circulation observed in later experiments with floats <28>.

Other results of geostrophic calculation are in Fig. 16b and c. These are made from STD data collected along part of the cross-section shown in Fig. 11b. The levels of no motion were chosen at (b) 200 m and at (c) 900 m. The direction of the computed geostrophic current in (c) agrees with the drift of the VCMs, indicating the deep extension of the anticyclonic gyre.

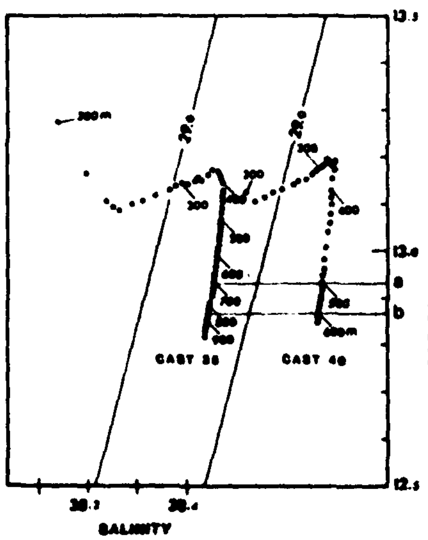


FIG. 8
θ-S DIAGRAMS FOR CASTS STD40 AND STD35, 8.5 km APART, DEMONSTRATING THE UPWELLING OF WESTERN MEDITERRANEAN DEEP WATER. Horizontal lines indicate waters of the same θ-S:
a) 710 m at station 35 and 500 m at station 40.
b) 850 m at station 35 and 600 m at station 40.

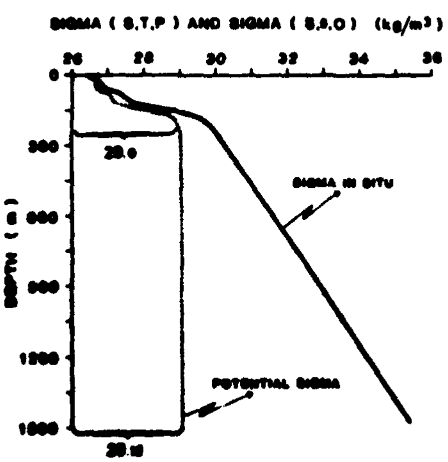


FIG. 9
WATER DENSITY IN THE ALBORAN SEA.
Sigma (S,T,P) = [Density(S,T,P)-1] × 1000. Potential density is a density of unit volume transferred adiabatically to the surface. Potential sigma, which represents real change in stratification (without adiabatic compression), shows only negligible change below 200 m depth.

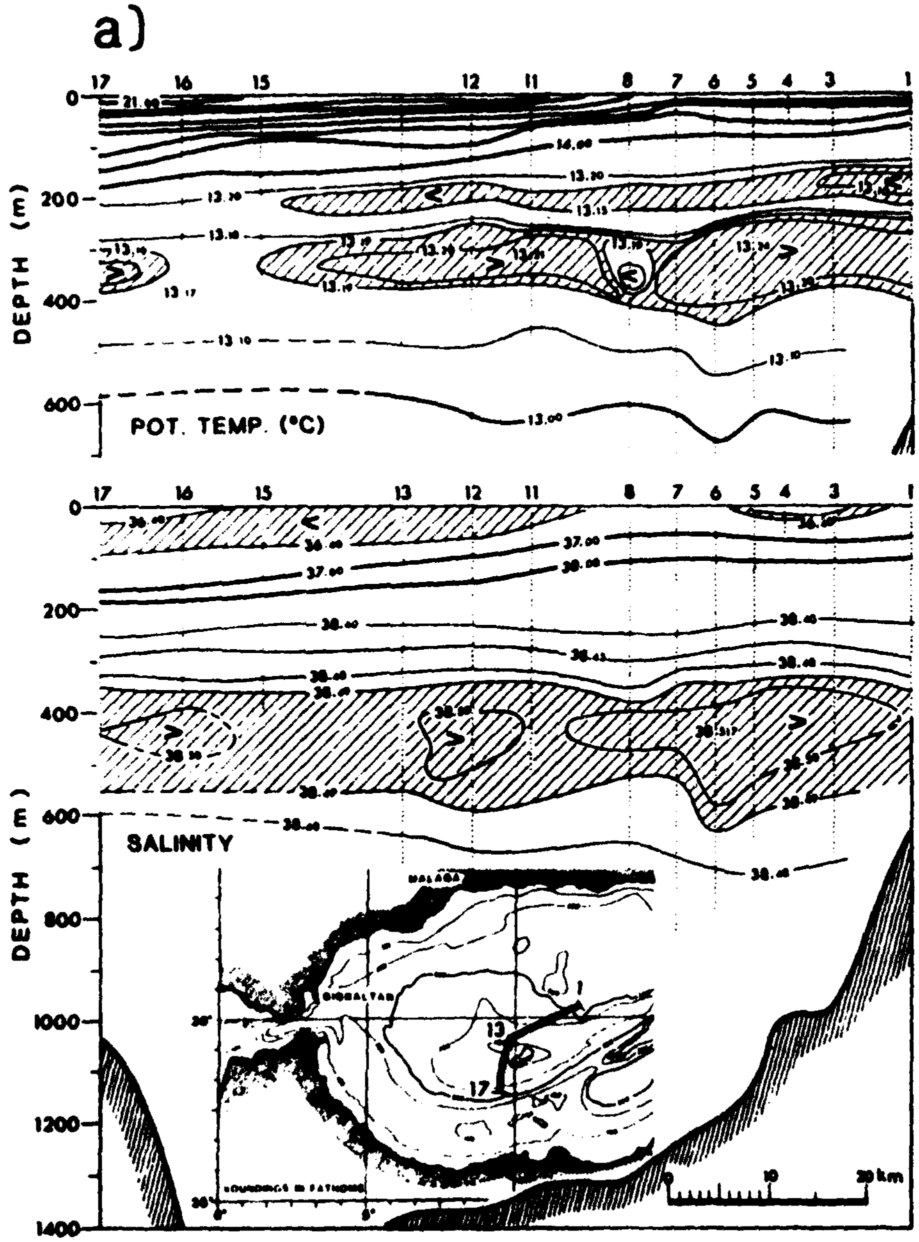


FIG. 10 CROSS-SECTIONS OF POTENTIAL TEMPERATURE AND SALINITY (CTD), JULY 1980.
a) Casts 1 to 17. The deep water does not rise along the northern slope of the deep Alboran Sea channel. It indicates that the strongest characteristics of the Intermediate Water are in the middle part of Alboran Sea.

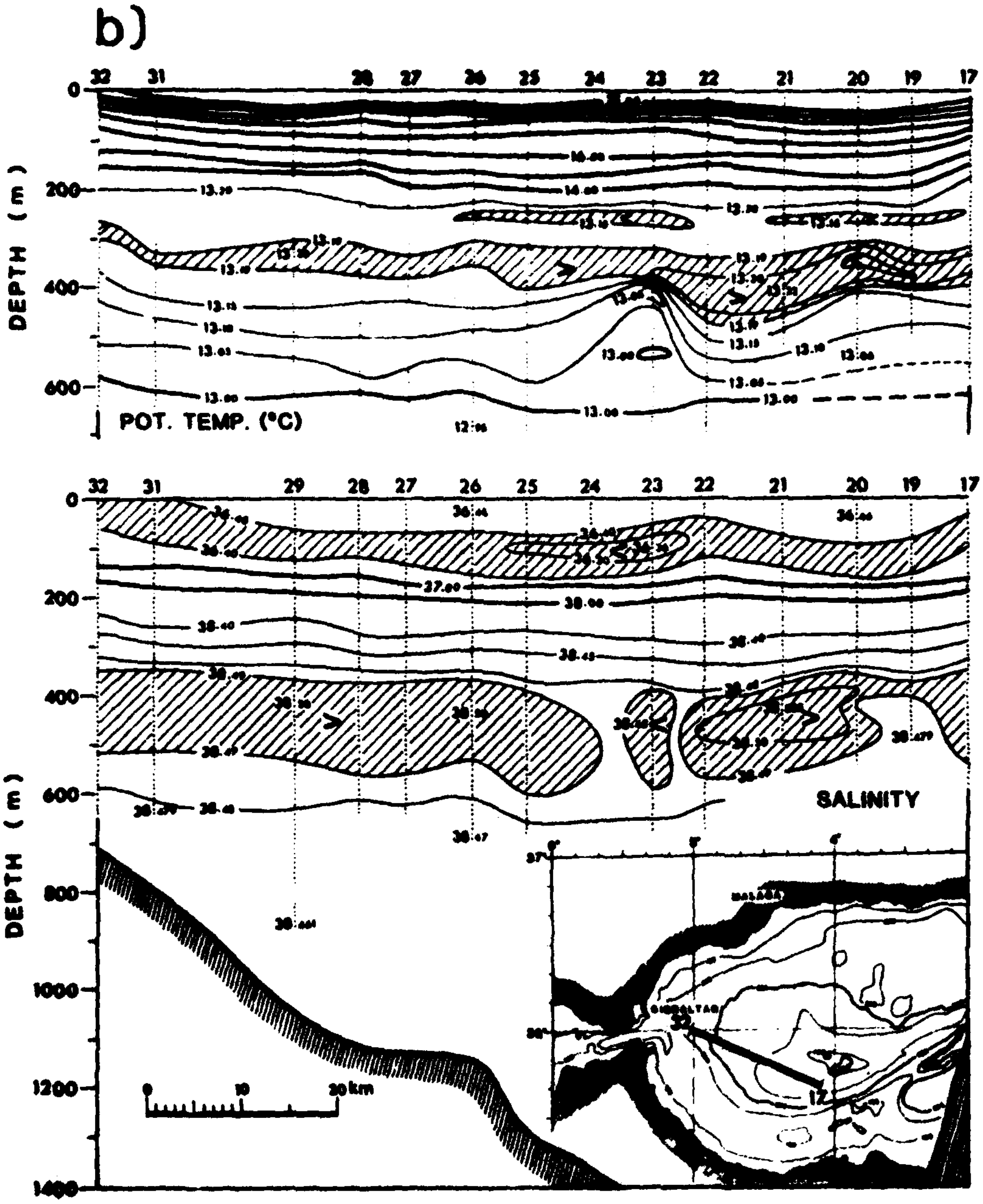


FIG. 10 (cont'd)
b) Casts 17 to 32. Surface isolines drop to a depth of more than 200 m, with probably some meandering near station 22. There is a layer of less saline water at 100 m depth, a front-like feature at 300 m near station 23, and pronounced characteristics of Levantine water east of it.

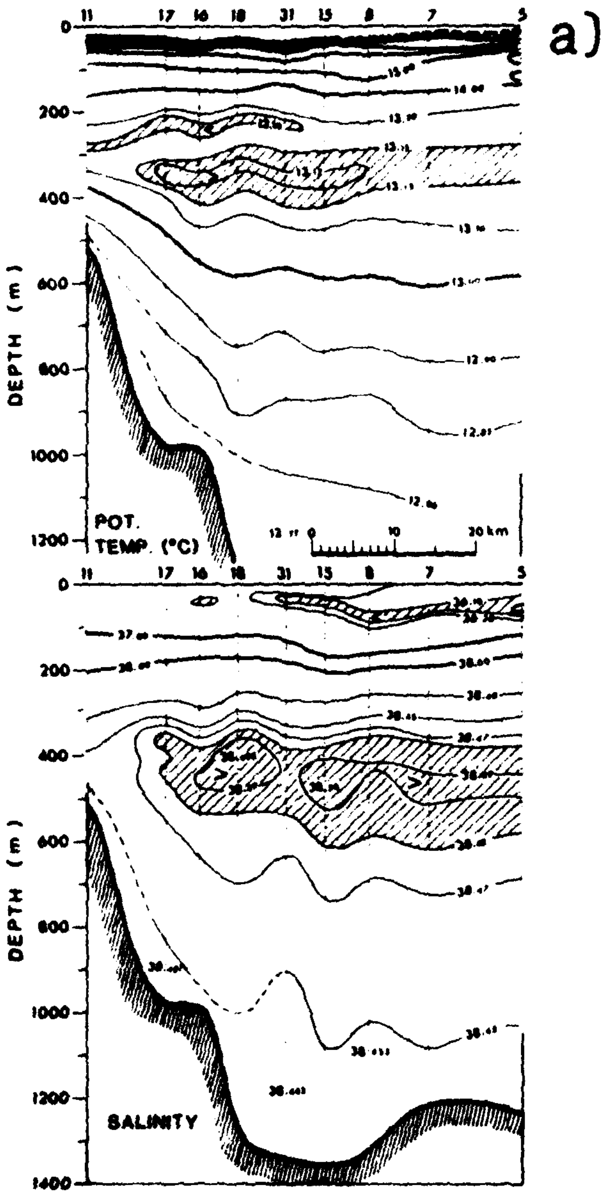


FIG. 11 CROSS-SECTIONS OF POTENTIAL TEMPERATURE AND SALINITY (STD), SEPTEMBER 1980. The isolines bend up towards the Moroccan continental slope. Levantine water with pronounced temperature and salinity maxima occurs around 400 m.

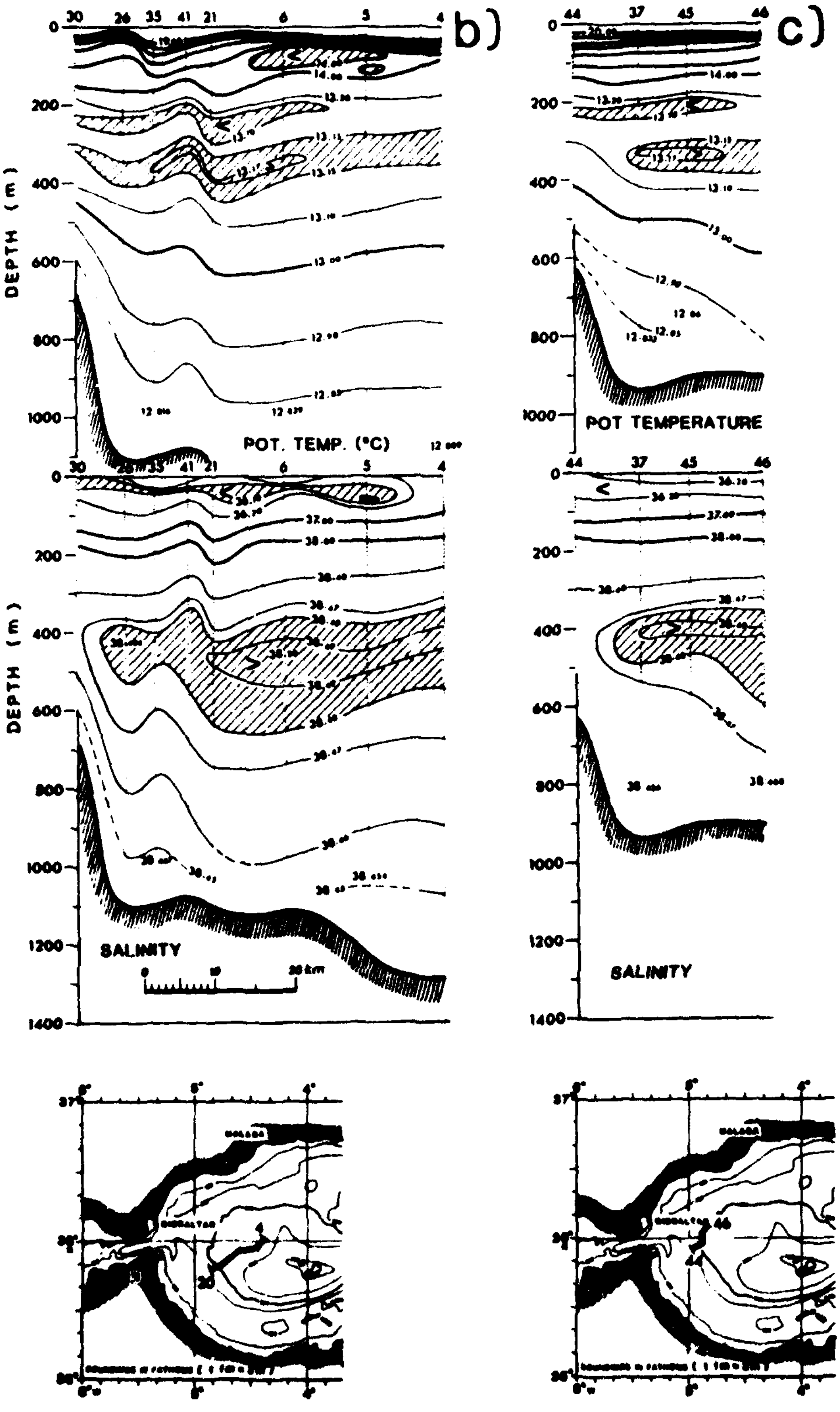
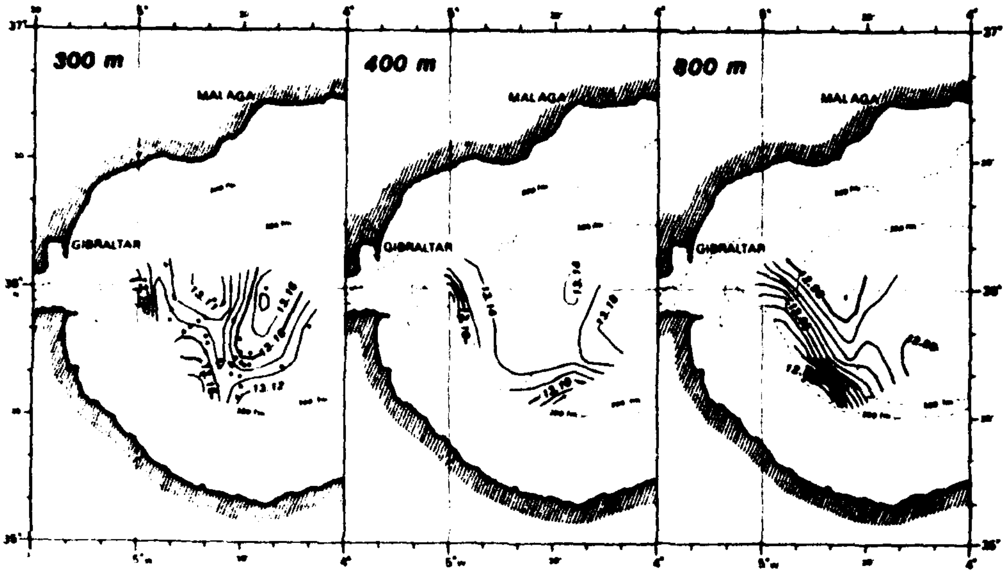
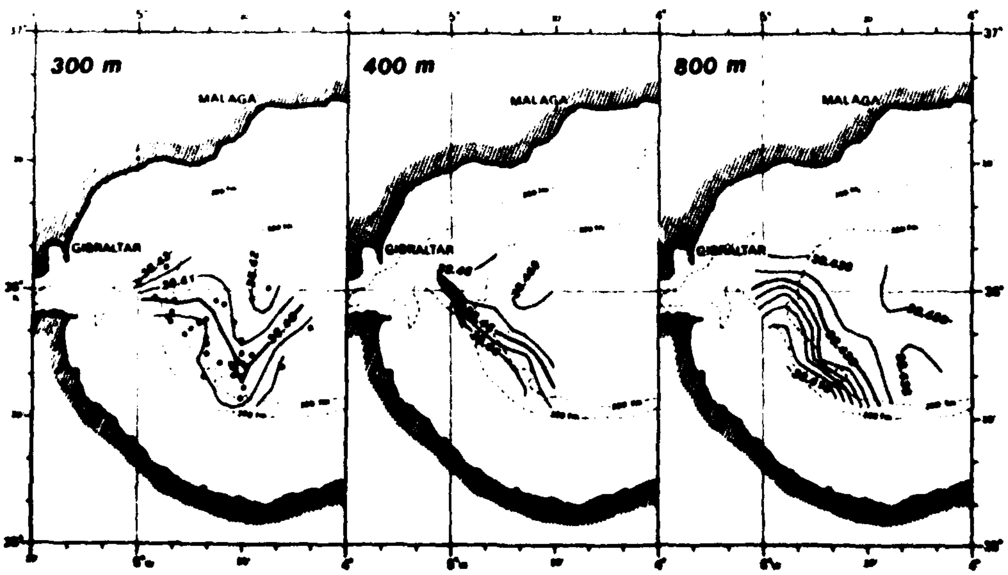


FIG. 11 (cont)

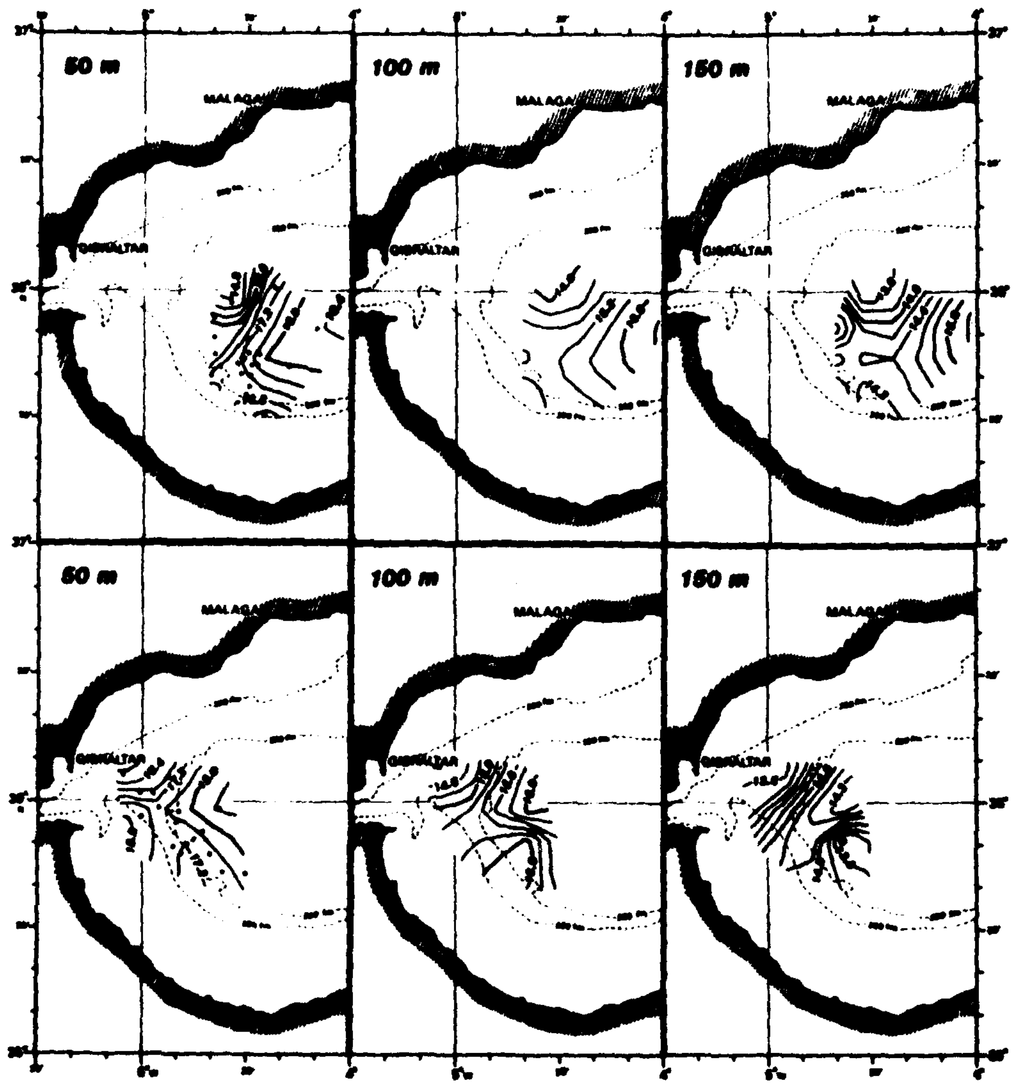


a) POT TEMPERATURE (°C)



b) SALINITY

FIG. 12 PARAMETERS OF THE DEEP WATER, SEPTEMBER 1980.
Contours are at depths of 300, 400 and 800 m. Dots indicate the STD casts.
a) Potential Temperature
b) Salinity



a) POT TEMPERATURE (°C)

FIG. 13 PARAMETERS OF THE UPPER LAYER, SEPTEMBER 1980
Contours are at depths of 50, 100, 150 m. Dots indicate the STD casts. Upper and lower sequences are of STD sets I and II (see Table 1) on 14-16 and 18-21 Sep.
a) Potential Temperature
b) Salinity (p. 26)
c) Dynamic Height Anomaly (p. 27)

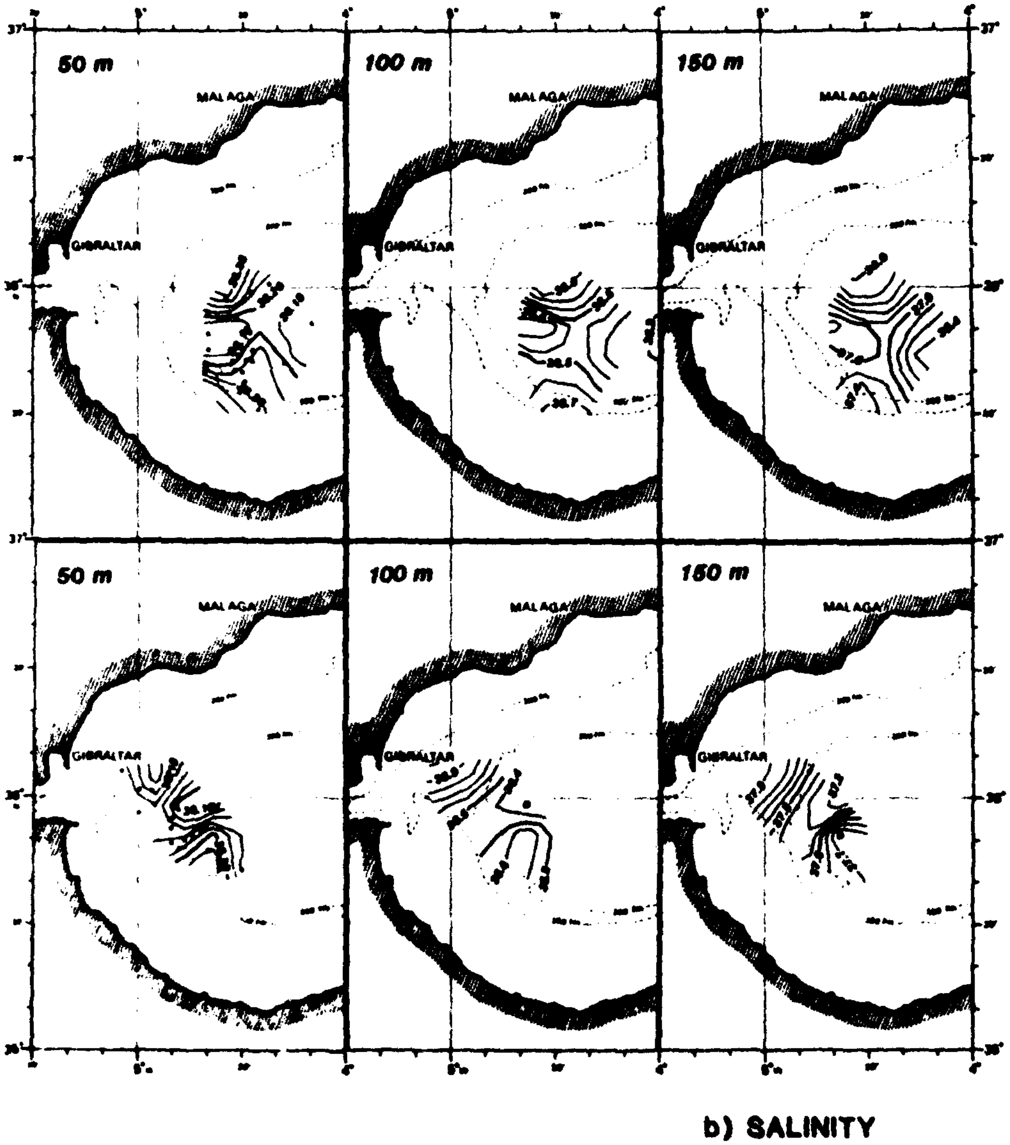
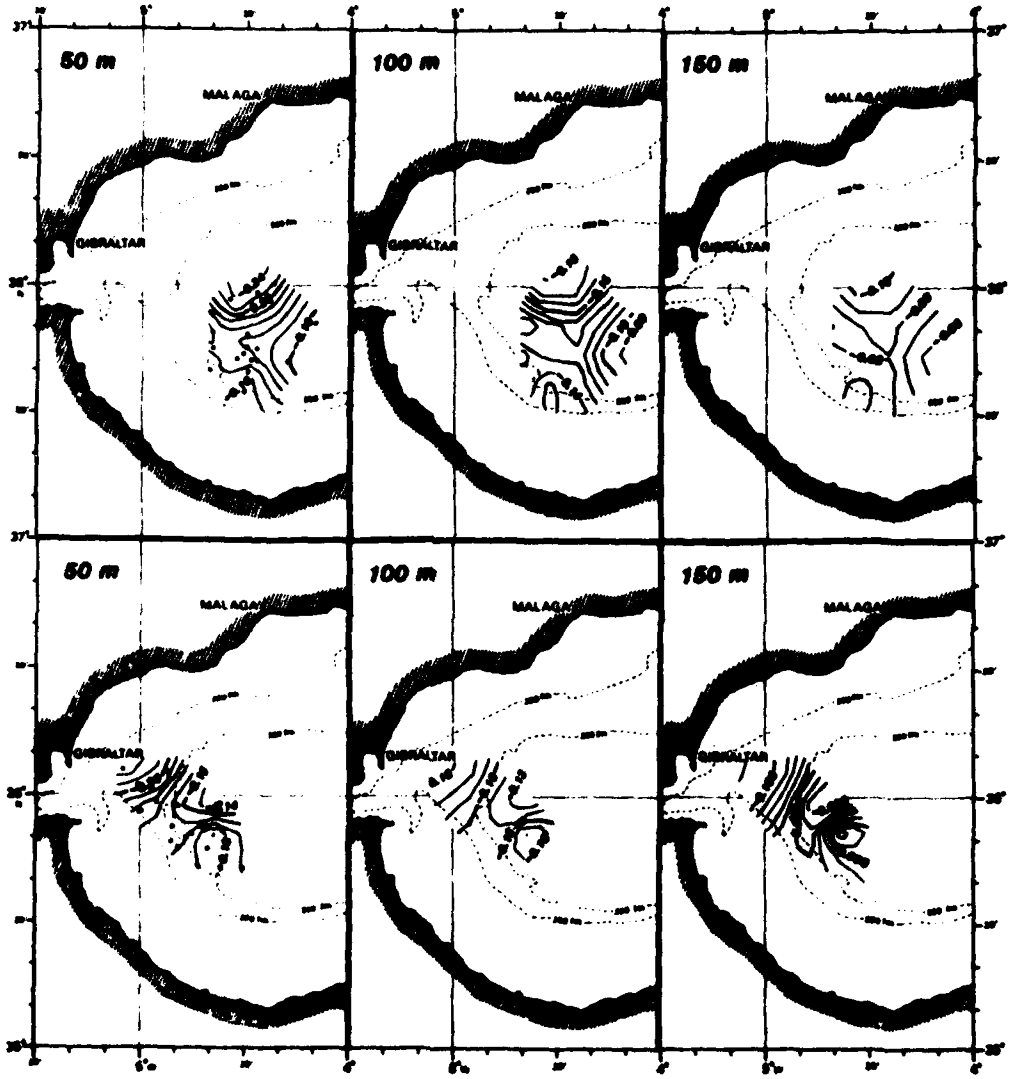

50 m
100 m
150 m
MALAGA
GIBRALTAR
50 m
100 m
150 m
MALAGA
GIBRALTAR
b) SALINITY

FIG. 13 (cont)



c) DYNAMIC HEIGHT ANOMALY (dynm)

FIG. 13 (cont)

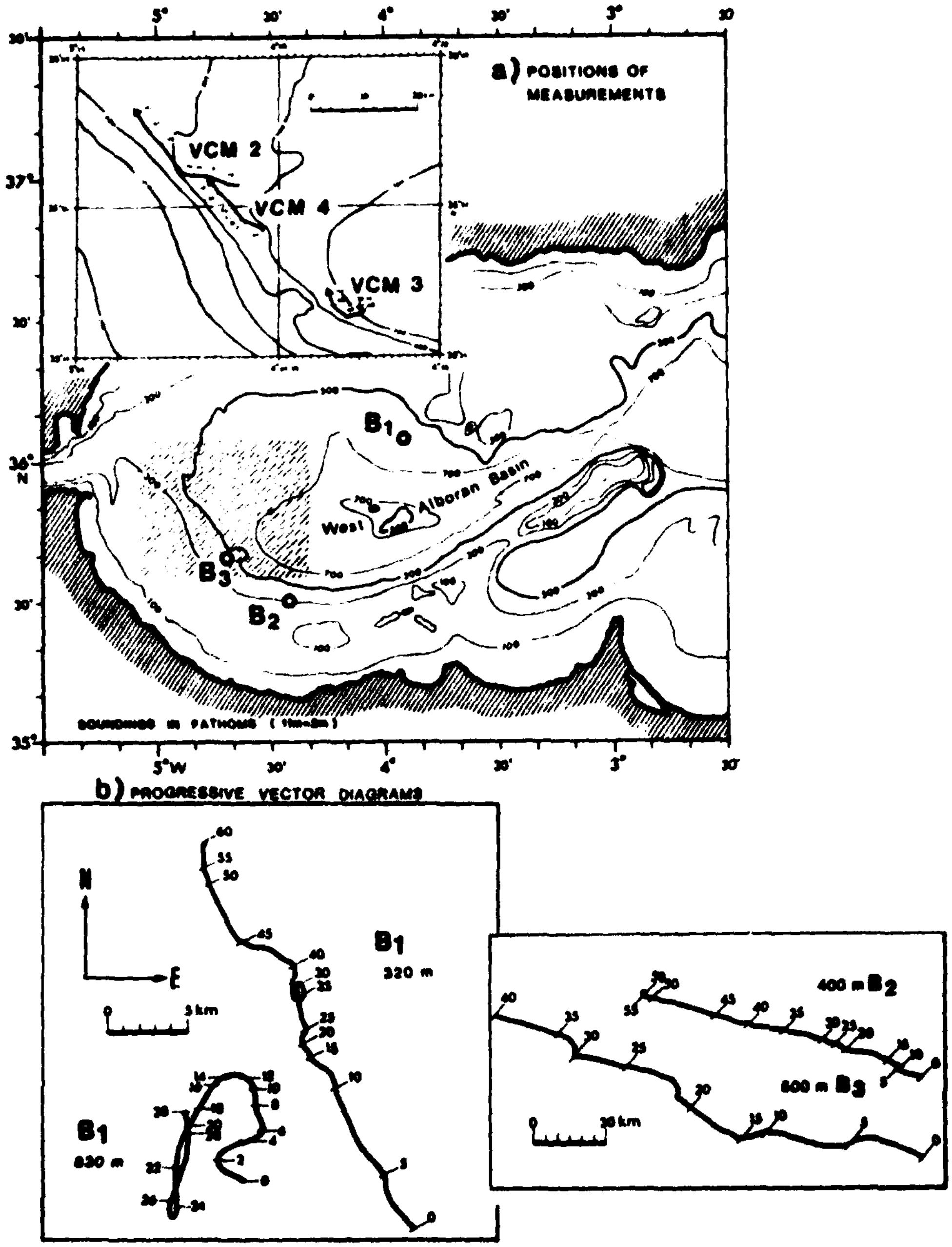


FIG. 14 CURRENT MEASUREMENTS, JULY AND SEPTEMBER 1980.

a) Positions of currentmeter moorings and the tracks of VCMs. B_3 indicates the position of the part of Bryden's currentmeter data coincident with SACLANTCEN's measurement. Numbers near VCMs signify hours when their locations were established starting from J. day 259.

b) Progressive vector diagrams for B_1, B_2, B_3. Numbers signify J. days (starting day 202). Scales for B_1 are different from B_2 and B_3.

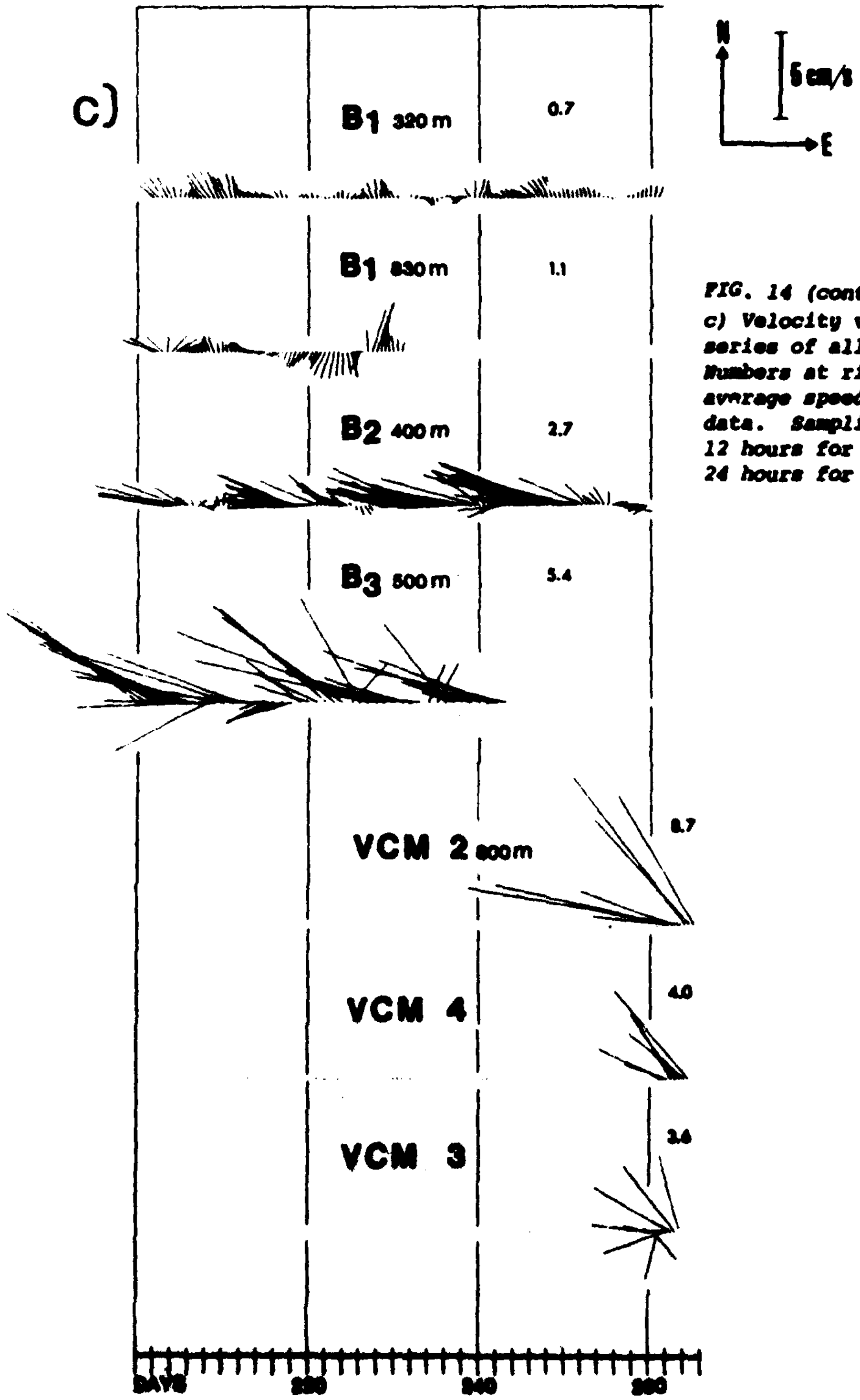


FIG. 14 (cont)
c) Velocity vector time series of all currentmeters. Numbers at right signify the average speed of plotted data. Sampling interval is 12 hours for B_1 and B_2 and 24 hours for B_3.

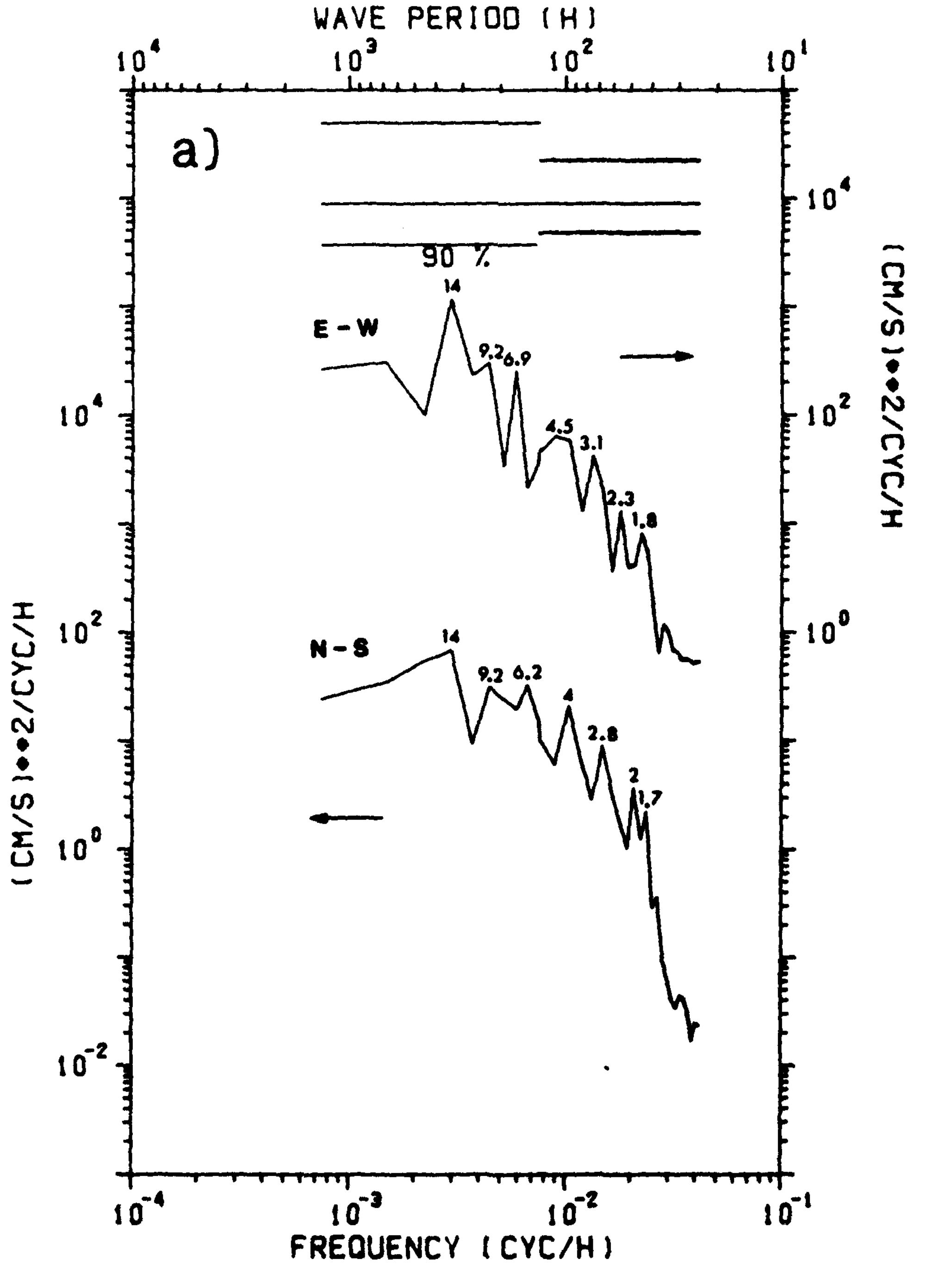


FIG. 15 SPECTRA OF VELOCITY COMPONENTS

a) Autospectra

Computed as an average from all currentmeters. E-W and N-S indicate components; numbers near peaks the associated period in days. 90% confidence limit of gaussian distribution is indicated.

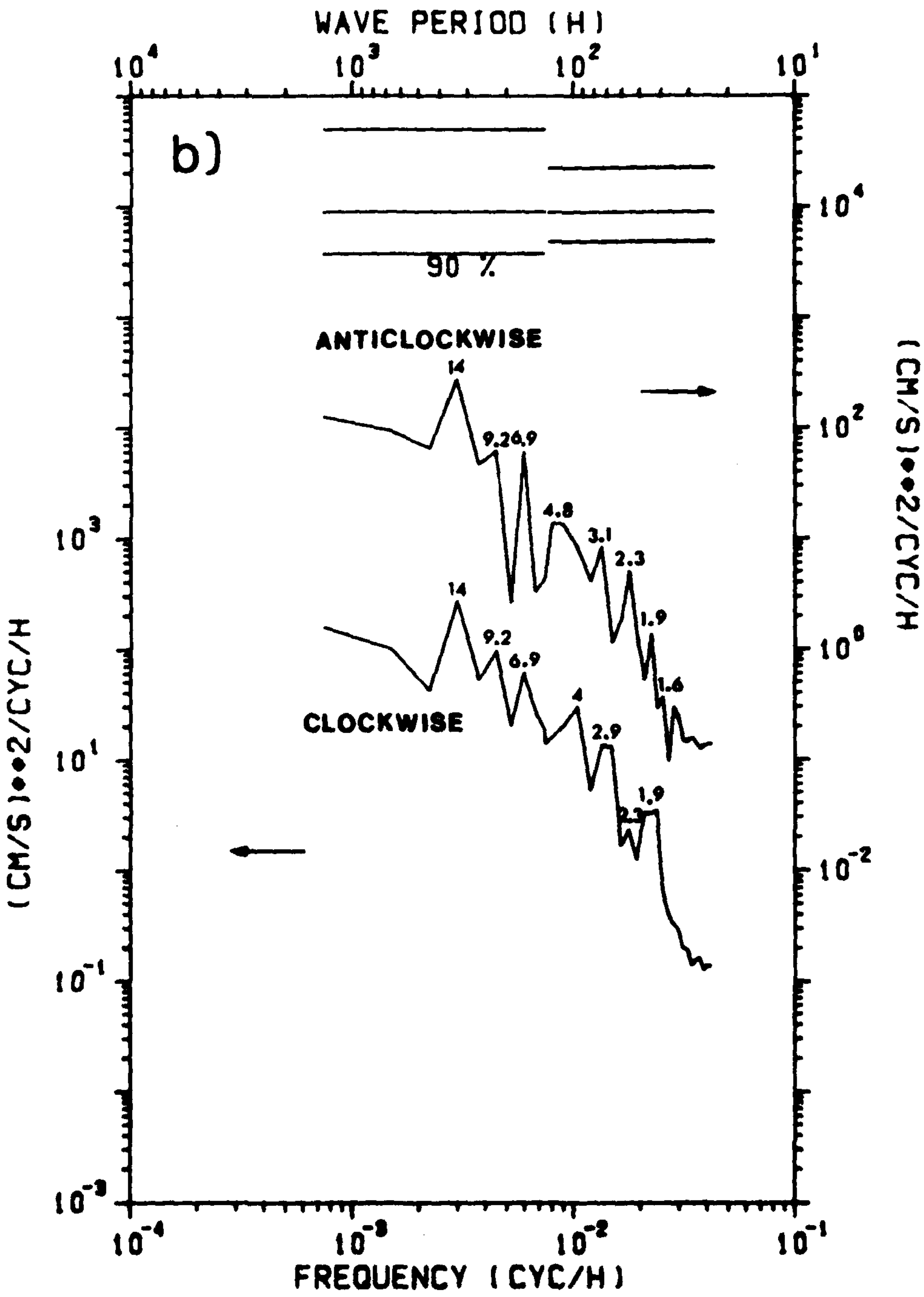


FIG. 15 (cont)

b) Rotary spectra

Computed as an average from all currentmeters. Numbers near peaks indicate the associated period in days. 90% confidence limit of gaussian distribution is indicated.

a)

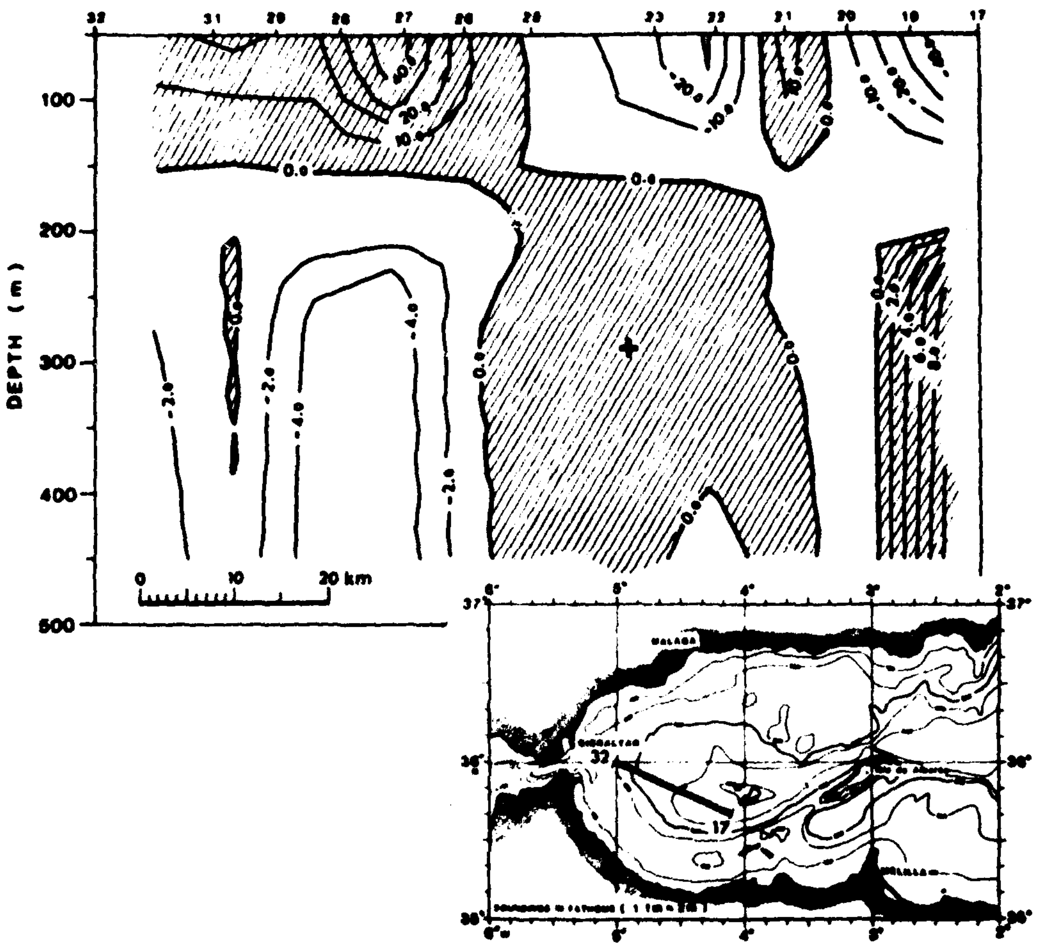


FIG. 16 CROSS-SECTION OF GEOSTROPHIC CURRENT (in cm/s)
a) Computed from the CTD data in Fig. 10b
b) Computed from some of the STD data in Fig. 11b. Level of no motion at 200 m
c) Computed from some of the STD data in Fig. 11b. Level of no motion at 900 m. Current direction agrees with the drift of the VCMs, indicating the deep extension of the anticyclonic gyre.

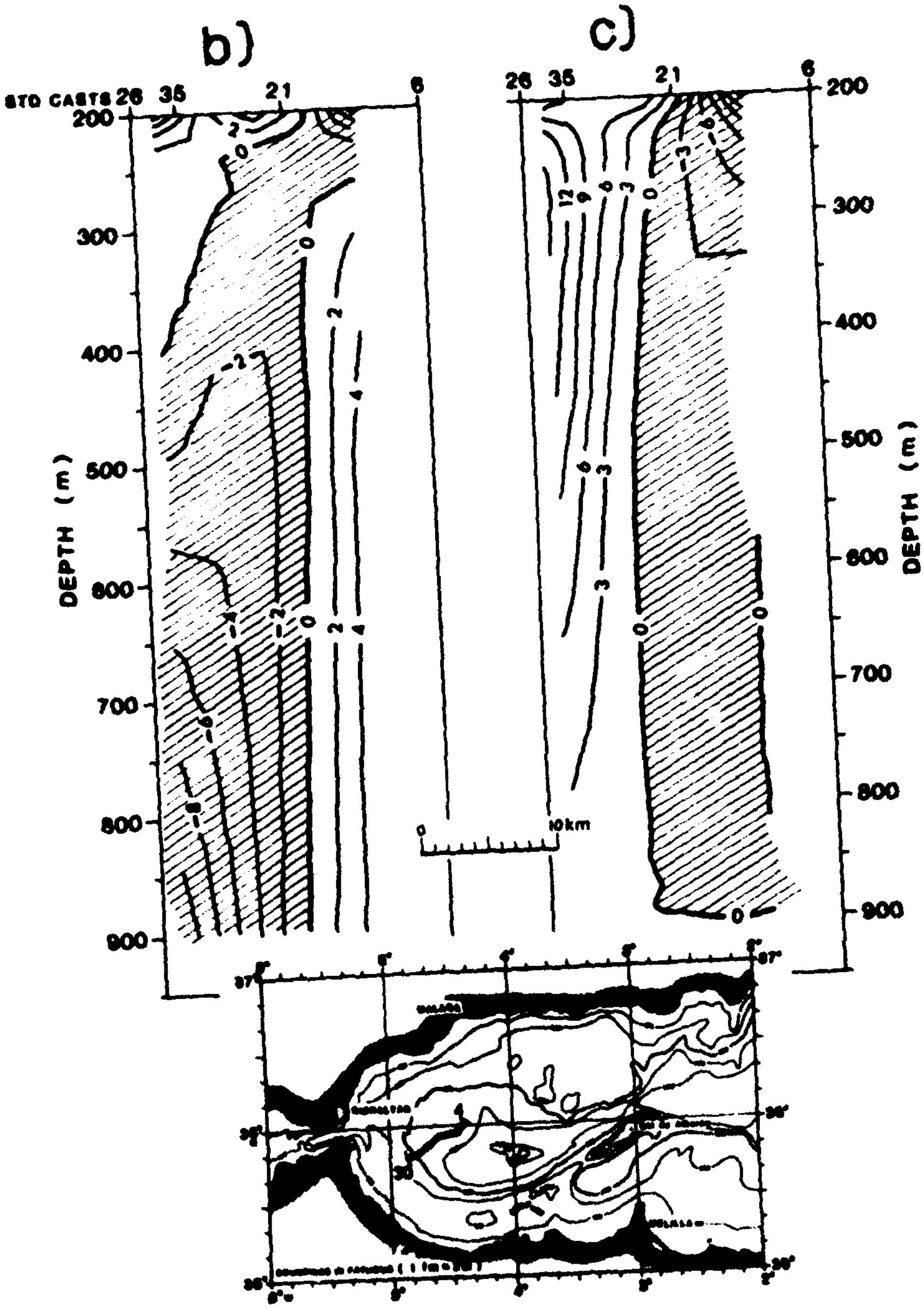

b)
c)
STD CASTS 26 35 21 6
26 35 21 6
DEPTH (m)
DEPTH (m)
200
300
400
500
600
700
800
900
0 10km

FIG. 16 (cont)

CONCLUSION

CTD and STD measurements in the Alboran Sea in July and September 1980 show the Western Mediterranean Deep Water sloping upwards against the Moroccan continental slope and its absence even in the northern slope of the deep Alboran channel where there is an inflow of this water from the east.

A comparison of the two sets of September 1980 STDs in Fig. 13 indicates that the upper anticyclonic gyre was probably shifted further east, as indicated by Set I. It also shows that the meandering feature was visible in all variables (salinity, potential temperature, and dynamic height) at the place where the permanent gyre is assumed to exist, moving to the west about 35 km in three days as indicated by Set II. Also, CTD casts taken in July (Fig. 10) indicate the meandering and the eastern shift of the anticyclonic gyre. Levantine water was clearly detectable in all cross-sections, with the strongest signal in the centre of the basin at CTD stations 1 to 8. Contours indicate a tongue of this water mass lying from northeast to south. The currents measured at 320 m at mooring B_1 did not show an anticyclonic tendency, their slow motion (about 1 cm/s) being to the northwest.

If the contribution to the Gibraltar outflow from the northern part of the Alboran Sea is negligible, as found by Bryden and Stommel <10>, there has to be a cyclonic return flow (as was later indicated in 1982 by floats). The deep flow (830 m) at the same position showed slow and variable motion to the northwest or south. On the contrary, the currents along the continental slope of Morocco were strong and flowed persistently towards Gibraltar, with their speed increasing in the western part. During the forty days when currents were measured contemporaneously with Bryden, they averaged 5.4 cm/s at 400 m at mooring B_2 (the easternmost mooring) and 6.0 cm/s at 500 m at mooring B_3. The vertical currentmeter VCM3 deployed about 16 km to the east of mooring B_3 showed a lower average speed of 3.6 cm/s and those deployed northwest of it moved with increasing average speed, VCM4 at 4.0 cm/s and VCM2 at 8.7 cm/s. They displayed a tendency to move towards the Moroccan slope from the easterly sites of their deployment. This bending of the VCMs' tracks and their high speed at B_3 indicated that the currrent was strongest on the slope. Measurements also showed that the current extended at least from 400 m (at B_2 position) to the bottom (VCMs at 800 m).

Bryden and Stommel <10> assumed that the anticyclonic gyre near the surface extends deep and that the current and sloping isolines along the Moroccan coast are formed by it. Our measurements show the existence of those features but the position and extension of the anticyclonic gyre in July and September is different from the expected one. Velocity spectra show several peaks, but the measurements are too short to achieve better confidence limits and the association with the causal phenomena is not known.

Sufficient information was obtained from these two cruises to conduct other cruises in winter 1982. The results of these cruises will be reported separately.

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KEYWORDS

ALBORAN SEA
CIRCULATION
DEEP WATER
GEOSTROPHIC CURRENT
MOROCCAN CONTINENTAL SLOPE
CTD
STD
ISOLINES
SALINITY
TEMPERATURE
ANTICYCLONIC GYRE
ROTARY SPECTRA
AUTOSPECTRA
CURRENT VELOCITY
THERMAL FRONT
EDDIES
CURRENT JET
OCEANOGRAPHY
WESTERN MEDITERRANEAN BASIN
REMOTE SENSING
SURFACE CIRCULATION
DYNAMICAL FORCING
EVAPORATION
STRAIT OF GIBRALTAR
PRECIPITATION
SALT BALANCE
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OUTFLOW
CORIOLIS FORCE
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ATLANTIC
ANTICYCLONIC CIRCULATION
MODELLING
LEVANTINE
VERTICAL CURRENT METER
VCM
GYRE
GROVES' FILTER
LOW-PASS FILTERING

MARSDEN SQUARE NUMBERS

109/51/52/53/54/55
109/61/62/63/64/65

FREQUENCIES

1500 Hz

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